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*Taguchi-methods,
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DEVELOPMENT FOR SOUND QUALITY OPTIMISATION BY TAGUCHI-METHODS

Characteristic that is hard to obtain in the calculation in product development. The sensory characteristic is often had such as sound quality, visual sensation and tactile sensation. The evaluation method for visualizing the determination of the customer is being established by applying Taguchi-methods and so on. The fact is still got many corresponds with the method of Try & Error as numbers of cases are small in order to optimize the properties. Therefore, the study was conducted of the method for optimization of sound quality by using the innovative tool using Taguchi-methods that newly developed. The research results are summarized as follows. (1) Sensory characteristic tuning method by using Taguchi-methods was calculated the values to be optimized in a few studies, and the result was equal to or greater than the result of specialists is carried out. (2) Commonly, the sensory characteristic of optimization is conducted with the method of Try & Error; moreover, it could be confirmed that leading to improvement of productivity by using this method even though it takes time to perform so as to optimize under changing in physical condition and environment.

1. INTRODUCTION

Recently, the acceleration and the cost saving for development have been a critical issue to the manufacturing industry. Thus application of the design and processing simulation has expanded as it is contributed to period shortening of product development without spending cost and taking time. Therefore, Taguchi-methods [1],[2] are used for making a decision of the optimum process conditions. However, these methods are not enough to develop a new product with short time, low cost, high quality and accuracy.

Furthermore, it is faced to a new issue at the manufacturing industry. As man may eventually use a product, the domain of sensitivities is significant such as hearing, a tactile sense, and vision. Though a tuning technique cannot be established completely, it is required substantial time in order to achieve the target. Even though tuning is implemented with various parameters, there are lots of cases about the technique of Try & Error.

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In this research, the software for innovation tool by using Taguchi-methods is developed and evaluated in order to determine the combination for the level of control factor as the highest level. There are two details in the innovation tool by applying Taguchi-methods.

The first trial is investigated for rough functions regarding the complete levels of all control factors, and important control factors and meaningless control factors are sorted by the several comments for second trial. Maximum, intermediate and minimum values for each level of the each control factor should be used for pursuit of all possibilities. The second trial is decided the optimum combination of the control factors in detail by applying only important control factors. The second trial is tried to obtain the best combination by using the optimum level of each control factor. The optimum condition regarding cooling system for cutting is investigated for evaluating this innovation tool in the experiment.

2. BRIEF OVERVIEW OF TAGUCHI-METHODS

The designer always desire to pursue accuracy and functionality at the design phase and set the optimum parameter. In Taguchi-methods, as shown on the Table 1, what equivalent to the design parameter is called "level of control factors" (A_1-D_3), the numerical measure to show the quality as the intended accuracy is called "characteristic value", the intended accuracy or the characteristic value is called Nominal-is-Best Response (NBR), the cause of coming up an error and a dispersion is called "noise factor" (N), the type or value of noise factor is called "level of noise factor" (N_{11}-N_{33}). It is very difficult to examine the all combination; therefore, the conditions are assigned with the orthogonal array which are used in Design of Experiments, the combination using the levels of minimum control factors is determined.

$$SN\ ratio\ (db) = 10 \log (\mu^2/\sigma^2) \tag{1}$$

$$Sensitivity\ (db) = 10 \log \mu^2 \tag{2}$$

Table 1. Control and noise factors in the Taguchi-method

Control factors				
Name	A	B	C	D
Levels	A_1	B_1	C_1	D_1
	A_2	B_2	C_2	D_2
	A_3	B_3	C_3	D_3

Noise factors			
Name	N_1	N_2	N_3
Levels	N_{11}	N_{21}	N_{31}
	N_{12}	N_{22}	N_{32}
	N_{13}	N_{23}	N_{33}

Experimenting or performing CAE analysis based on the combination, the error and the dispersion are generated in NBR as a result because the noise factor varies according to the level. As a result, two or more NBR are calculated at every combination by using the levels of the minimum control factor. The average value (μ) and the standard deviation (σ) are calculated, finally, the Signal to Noise (SN) ratio and the sensitivity of the nominal-is-best response are obtained by the equation (1),(2).

Table 2. Orthogonal array, SN ratio and sensitivity in the Taguchi-methods

	Control factors				*SN ratio (db)*	*Sensitivity (db)*
No.	*A*	*B*	*C*	*D*		
1	A_1	B_1	C_1	D_1	$SN_{A1 \cdot B1 \cdot C1 \cdot D1}$	$S_{A1 \cdot B1 \cdot C1 \cdot D1}$
2	A_1	B_2	C_2	D_2	$SN_{A1 \cdot B2 \cdot C2 \cdot D2}$	$S_{A1 \cdot B2 \cdot C2 \cdot D2}$
3	A_1	B_3	C_3	D_3	$SN_{A1 \cdot B3 \cdot C3 \cdot D3}$	$S_{A1 \cdot B3 \cdot C3 \cdot D3}$
4	A_2	B_1	C_2	D_3	$SN_{A2 \cdot B1 \cdot C2 \cdot D3}$	$S_{A2 \cdot B1 \cdot C2 \cdot D3}$
5	A_2	B_2	C_3	D_1	$SN_{A2 \cdot B2 \cdot C3 \cdot D1}$	$S_{A2 \cdot B2 \cdot C3 \cdot D1}$
6	A_2	B_3	C_1	D_2	$SN_{A2 \cdot B3 \cdot C1 \cdot D2}$	$S_{A2 \cdot B3 \cdot C1 \cdot D2}$
7	A_3	B_1	C_3	D_2	$SN_{A3 \cdot B1 \cdot C3 \cdot D2}$	$S_{A3 \cdot B1 \cdot C3 \cdot D2}$
8	A_3	B_2	C_1	D_3	$SN_{A3 \cdot B2 \cdot C1 \cdot D3}$	$S_{A3 \cdot B2 \cdot C1 \cdot D3}$
9	A_3	B_3	C_2	D_1	$SN_{A3 \cdot B3 \cdot C2 \cdot D1}$	$S_{A3 \cdot B3 \cdot C2 \cdot D1}$

This method is for estimation of SN ratio and Sensitivity regarding all combinations of each level. For example, four control factors (A-D) are set. The equation (3) shows the estimate of the SN ratio ($SN_{A3 \cdot B2 \cdot C3 \cdot D1}$), the equation (4) shows the Sensitivity ($S_{A3 \cdot B2 \cdot C3 \cdot D1}$) under the condition, A_3, B_2, C_3, D_1 of the combination by using the levels of the control factors which has not been performed the trial based on the orthogonal array.

$$SN_{A3,\ B2,\ C3,\ D1}=SN_{A3}+SN_{B2}+SN_{C3}+SN_{D1}-(4-1)SN_{ave} \tag{3}$$

$$S_{A3,\ B2,\ C3,\ D1}=S_{A3}+S_{B2}+S_{C3}+S_{D1}-(4-1)S_{ave} \tag{4}$$

SN_{ave} is shown the average value of the SN ratio and S_{ave} is also shown the average value of the sensitivity to all control factors and the levels. In addition, the last constant four on the right side for the equation (3), (4) are mentioned the numbers of all control factors.

SN_{ij} and S_{ij} are able to calculate by using the orthogonally with the SN ratio and the sensitivity of the Table 2.

Taguchi-methods can be decided the value effectively of all level's combination of control factors. This research makes more developments, and the best price can be calculated effectively and easily.

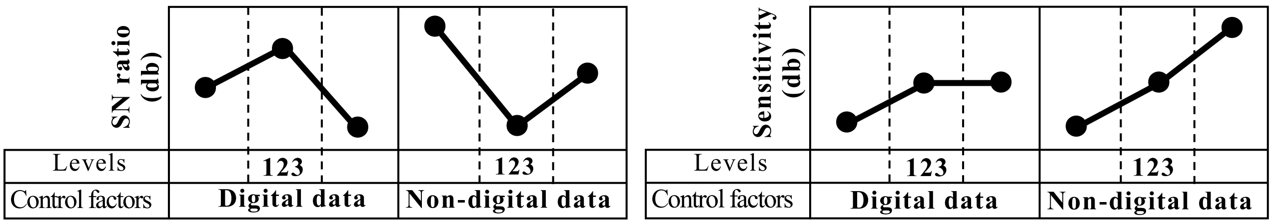
3. DEVELOPMENT OF INNOVATION TOOLS

3.1. EXPLANATION OF THE SOFTWARE FOR INNOVATION

Determining the value of level is left to the developer experience in the second trial that based on the first trial result as an issue even though Taguchi-method is known to be that based on the first trial result as an issue even though Taguchi-method is known to be able to use effectively in industries. Therefore, there is a case that the trial is repeated several times if the selection of value is wrong. Thus the software which makes it possible to develop industrial product rapidly and inexpensively according to search the optimal combination of control factors for the best function in a short time by using Taguchi-methods. Specifically, the software is calculated the factorial effect figures of the SN ratio and the sensitivity by Taguchi-methods. Regarding the complete assumed events, it is affected the function (intended characteristic value) as control factors in the first trial and decides the optimal control factors and the level for the second trial. Then it is confirmed if the combination is optimal in the second trial. The process which is decided the optimal control factors and the level for the second trial is the original important part [3].

Table 3 Several examples for the control factors

Digital data		**Non-digital data**	
Item of the control factor	Its properties	Item of the control factor	Its properties
Size, Weight, Material and so on	Design parameters	Product, Company, Country,	Individual data
Manufacturing condition, Measuring condition, Experimental condition	Action condition	National character, Worker, Human nature, Animal, Organic matter and so on	Personal data
Temperature, Humidity, Air pressure, Weather, Season and so on	Environment condition		



(a) SN ratio ($=10log(\mu^2/\sigma^2)$) (b) Sensitivity ($=10\ log\mu^2$)

Fig. 1. Effective figures of SN ratio and Sensitivity

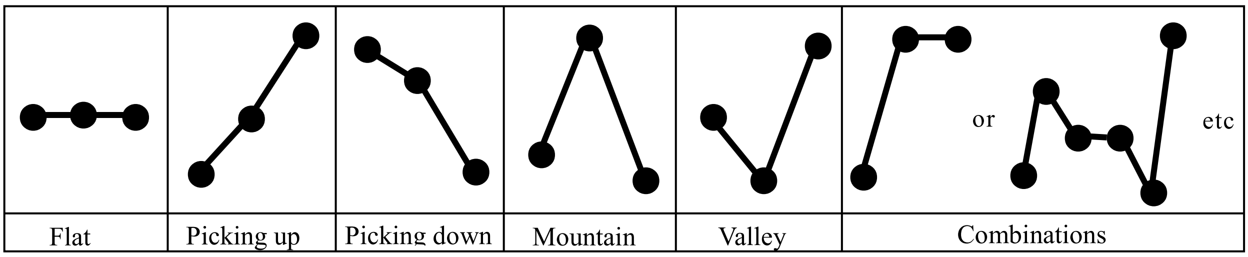
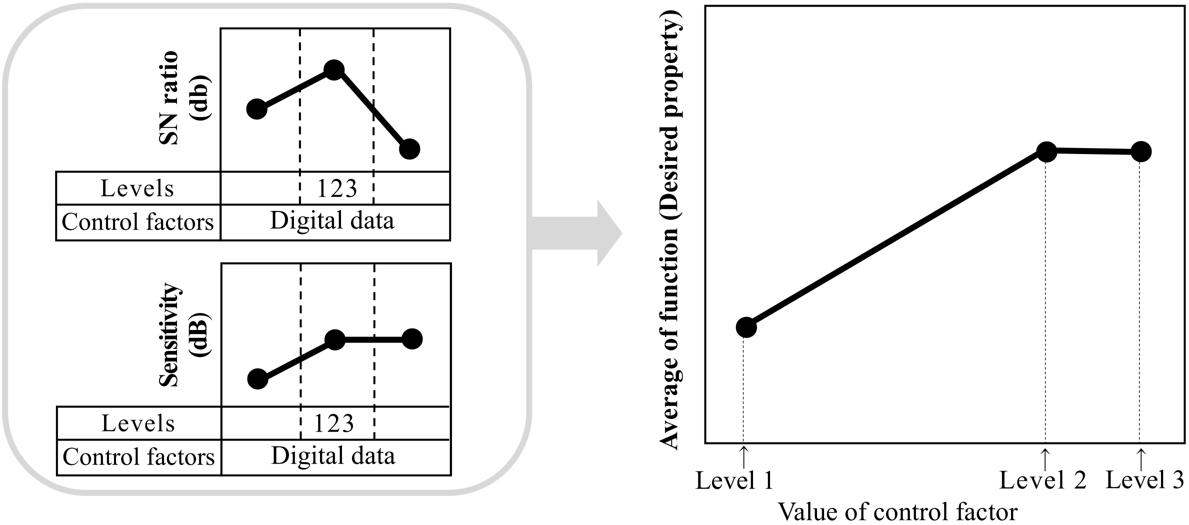


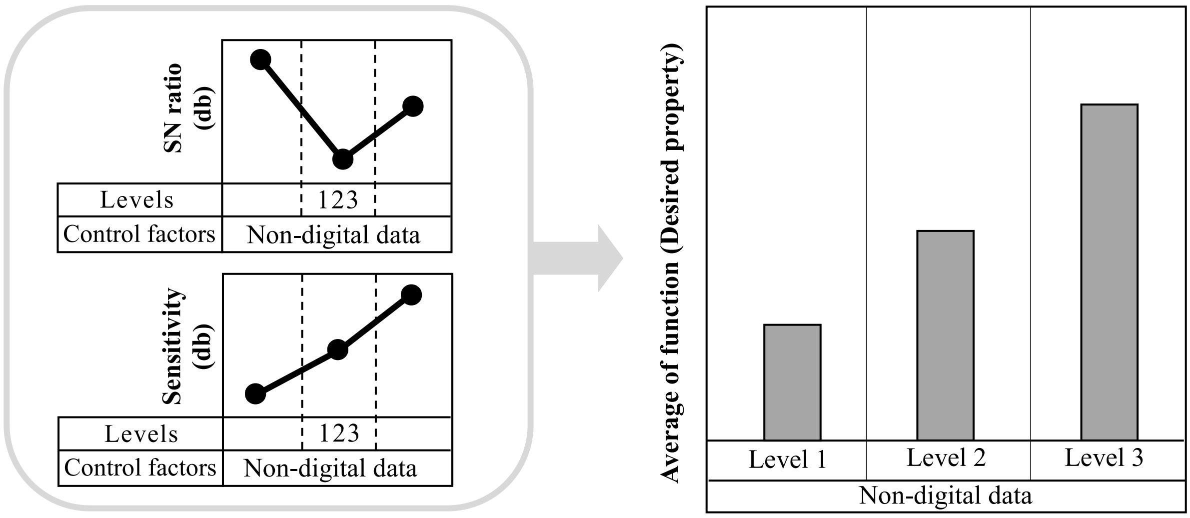
Fig. 2. Types of curve in effective figures of SN ratio and Sensitivity

As the Table 3 shows that control factors are divided into the digital data and non-digital data. In order to input (static characteristics) both of them to Taguchi-method, the factorial effect figures of the SN ratio and sensitivity are obtained. These graph forms of the factorial effect figures, as the Table 2 shows, are 5 types of combination of flat, upward-sloping, downward-sloping, inverted V and V. According to these differences, the range of searching for each level of control factors is changed to the second trial.

The difference between digital and non-digital data is depended on whether abscissa axis is digital or not. Re-plotting Fig. 1 and Fig. 2 by calculating the average and standard deviation of the characteristic value of each control factor's level by using the equation (1),(2) and Fig. 3 are represented (an example of the average of characteristic value is on the axis of ordinate). As Fig. 3 shows, control factors are represented which digital data with the line graph and non-digital data with the bar graph. The standard deviation also can be on the axis of ordinate.



(a) In the case of digital data for the control factor



(b) In the case of non-digital data for the control factor

Fig. 3. Effective figures of SN ratio and Sensitivity

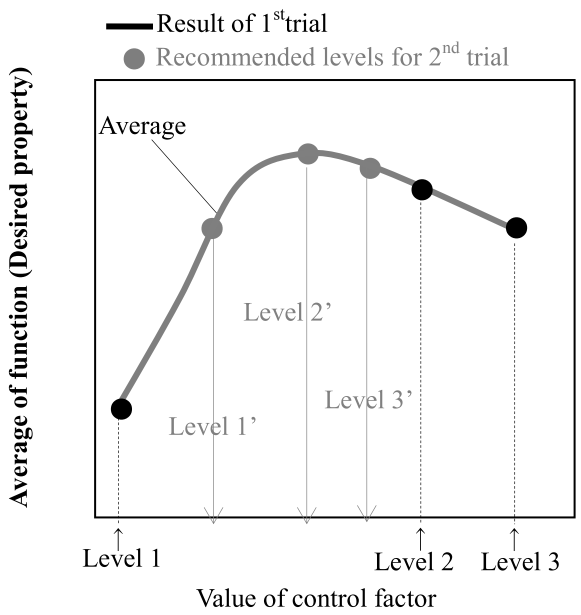
As each level is not always distributed value when the inputted control factors are digital data, it is common that the interval of each level is not distributed. According to convert the factorial effect figures from the Fig. 1 into the Fig. 3, it is tended to image physically the influence of each level for control factor. Moreover, the relation between the magnitude relationship and the axis of ordinate value can be perceived a physical amount correctly.

Table 4 Kinds of approximate curves regarding curve fit for first data in the software

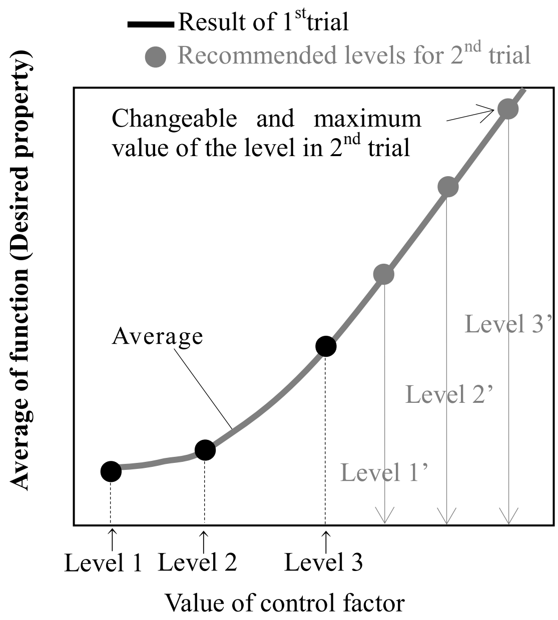
(1) Exponential approximation	(4) Polynomial approximation
(2) Linear approximation	(5) Radical approximation
(3) Logarithmic approximation (with degree)	

Moreover, in case of the line graph of digital data as the Fig. 3, the relation between each level of each control factor in the first trial can be smoothed by curve fit with five types of approximating method as the Table 4.

The optimum levels of the control factors for the second trial are decided by applying the results of the first trial. The method for selection of the optimum levels of the control factors is shown in Fig. 4. In the explanation, it is supposed that the larger function is desired for the designer. The curve of Fig. 4a has a mountain shape of graph, and there is the optimum level of the control factor in the first trial. Therefore, new level 2’ is below in the top of the mountain, new level 1’ is located in middle between the old level 1 and the new level 2’, and new level 3’ is located in middle between the new level 2’and the old level 2.



(a) Inside estimation



(b) Outside estimation

Fig. 4. Recommendation of the levels for 2nd trial using the results of the 1st trial

Level 1’, level 2’ and level 3’ are the optimum levels for the second trial. Moreover, the curve of Fig. 4b has an ever-increased shape of graph, and there is the optimum level of his control factor in the first trial correctly. Therefore, new level 3’ is decided as largest value, new level 1’ and new level 2’ are located where divided three equal parts between the new level 3’and the old level 3. The operator for the software can selected standard deviation for vertical axis and estimate stability for the noise factors.

3.2. EXPLANATION OF THE EVALUATION METHOD OF SENSORY CHARACTERISTIC

Usually, the Sensory Characteristic Tuning Method is tuned with the alternative characteristic. For example, in order to make a quality sound, the development which is improved the characteristics such as a frequency response characteristic, S/N Ratio (Signal Noise Ratio) and the THD+N characteristic as referred Fig. 5.

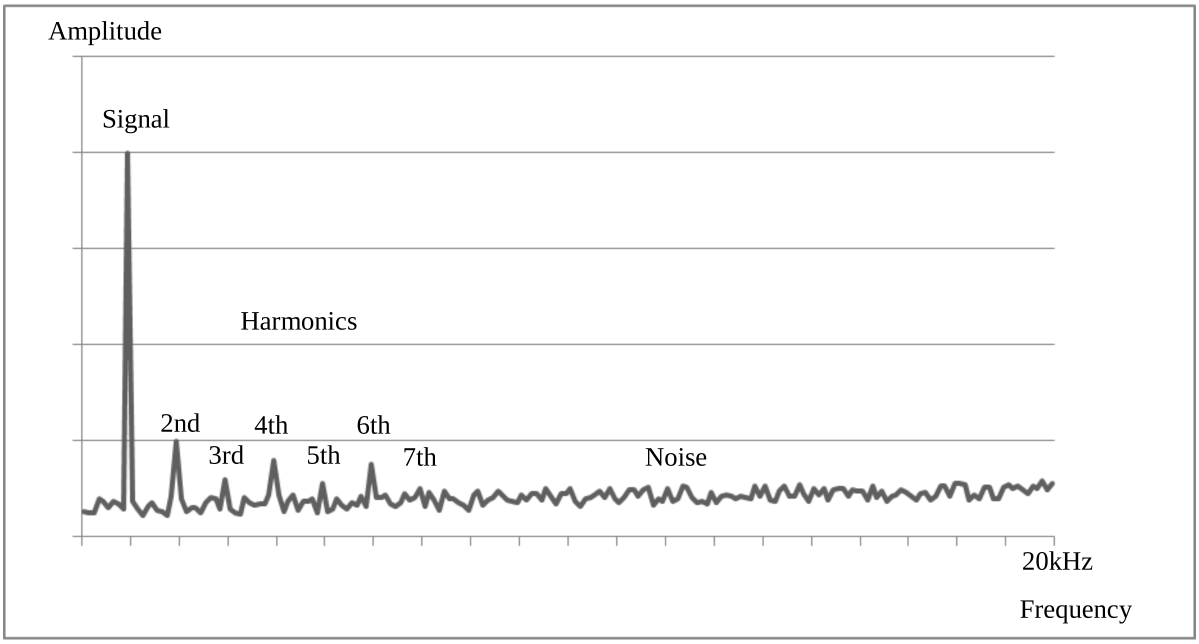


Fig. 5. Explanations of THD+D (Total Harmonic Distortion + Noi

However, these characteristic are static characteristic by the single signal at the specific condition. Often there is a difference in the quality of the sound that their values and human being feels in the actual sound source which is compounded continuous frequency. Also, these characteristics would be changed due to fluctuations in the power supply. The impedance, the level of a power supply and fluctuation of grand level are occurred when circuit diagram is wired in advance. Since these are complicated composition, it is also difficult for CAE to calculate.

Therefore, it is tuned the constant of circuit by Sound Meister while listening to the sound in advance. The way of tuning is depended on knowledge of each individual, but it is difficult to manuals. In this research, it is an object to make tuning more efficient by applying the innovation tool which cannot be manuals.

It has been found when human being listen to continuous sound, the difference between listening sound and the true value of the sound are considered as the vector difference of the m-dimensional [4]. Therefore, when listen in the columns is defined as X_d and true value in the column is defined as X_s , the difference equation is following equation (5).

$$\Delta(R) = m^{-1/2} (\sqrt{\Sigma_{i=1}^{m} x_{di}^{2}} + \sqrt{\Sigma_{i=1}^{m} x_{si}^{2}}) \quad (5)$$

By the above, human being can be captured RMS (Root Mean Square) as difference in sound. As an indicator, when human being evaluates the sound, there is an indicator such as senses of bass, treble and noise, etc. It is classified as a Table 5, and these values are considered as RSM values. Thus, the comprehensive judgment shall be performed due to calculate with the equation (6).

Table 5. Class zing and point of various indices

	Excellent	Good	Fair	Minimum Passing	Failed
Score (x_i)	5	4	3	2	1

$$\text{Evaluation Score} = \sqrt{\Sigma_{i=1}^{n} x_i^{2}} \qquad n = \text{The number of indices} \quad (6)$$

Based on this theory, an actual product is evaluated which is based on eight indicators on Fig. 6. The pass-fail judgment results of the product and this method results are matched.

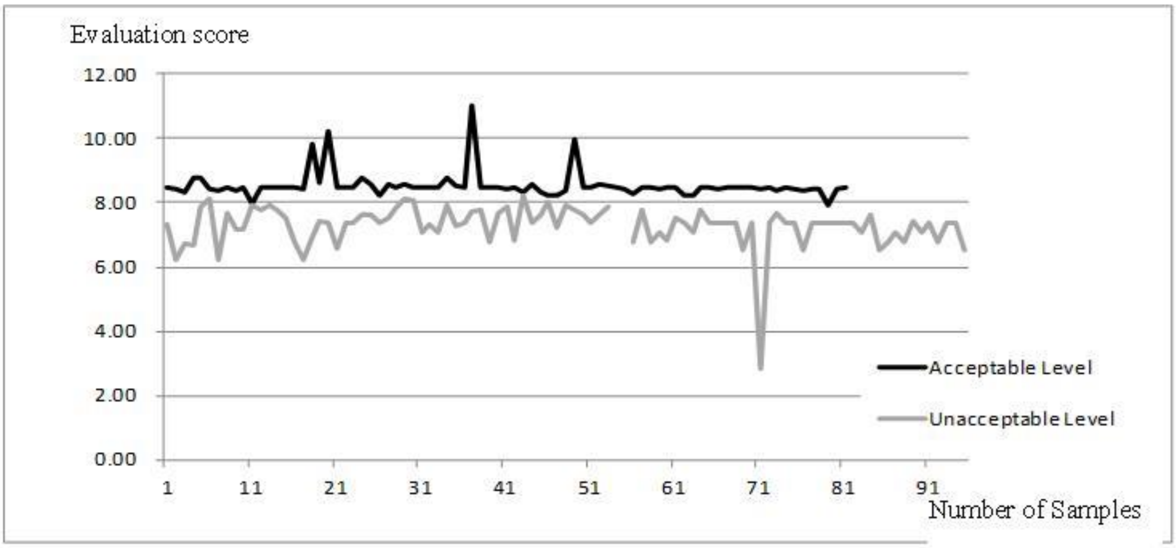


Fig. 6. Result of the determination in the RMS value

4. RESEARCH THROUGH THE OPTIMIZATION OF THE SOUND QUALITY

4.1. CONTROL FACTOR, NOISE FACTOR, AND MANUFACTURE CONDITIONS

In the end, the optimization of the Sound Quality of Optical Disc Drive is used for the evaluation effectively with the innovation tool. It is aimed at improving the quality of the Optical Disc Drive. Experimental system is shown in Fig. 7. Optical Disc Drive System cannot be operated independently so that the system is necessary for the Sound Quality evaluation to connect to standard Controller, Amplifier and Speaker exteriorly.

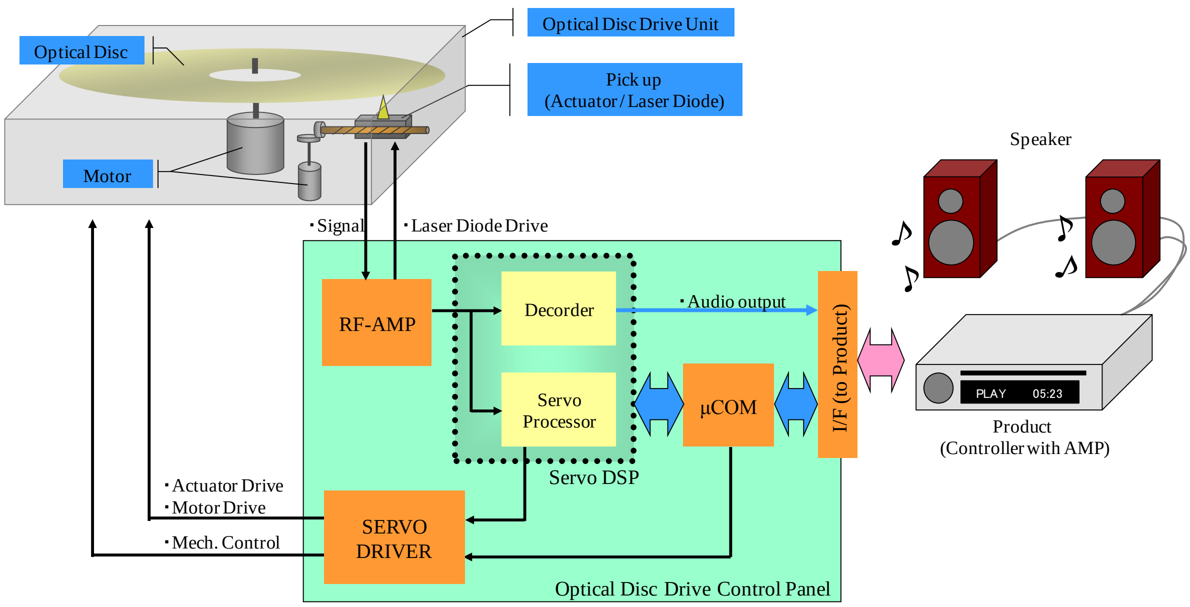


Fig. 7. Optical Disc Drive System Block Diagram

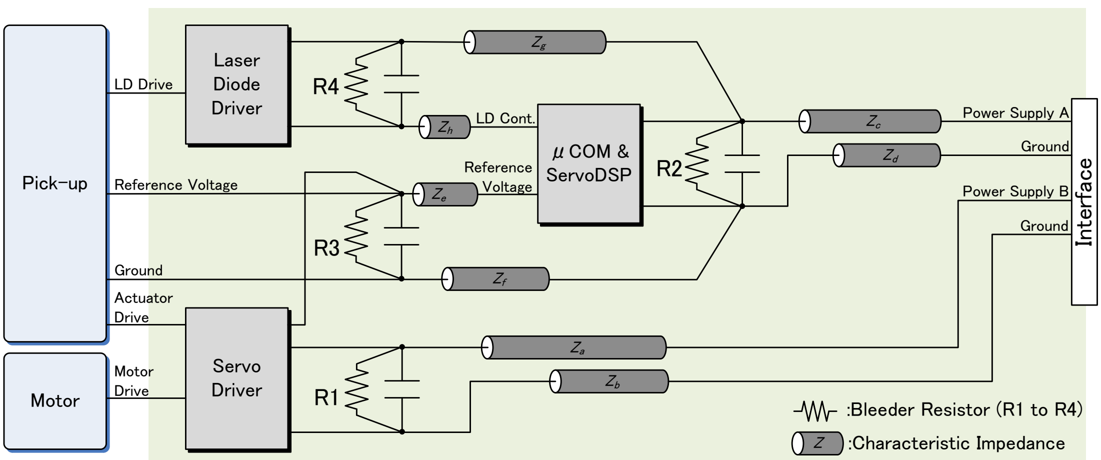


Fig. 8. Optical Disc Drive Control Panel Circuit

There are some factors which are determined the Sound Quality of Optical Disc Drive. Therefore, design consideration in deliberation of factor is performed from early stages of the design. In the optimization phase, it can be changed only small parts mainly Resistors and Capacitors on the circuit board according to the design restriction.

As one of the factor to determine Sound Quality, it is generally known that affect to the impedance characteristic by a circuit pattern and the current flowing along load. Usually, the current impact cannot be detected by observation of the waveform. In the theory, dynamic characteristic is normally identified to have an impact to Sound Quality so that it is possible to improve Sound Quality in order to stabilize the current flowing same load.

Experimental circuit is shown in Fig. 8. Optical Disc Drive on Control Panel is used for this experiment, and it is wired to be able to arrange Bleeder Resistor (R1, R2, R3, and R4) in parallel with capacitor at power supply unit of four loads which has impact to Sound Quality. Also, there is a possibility to vary the impedance of the circuit. Adjustment of the Sound Quality is enabled by the constant of this Bleeder Resistor. In this experiment, Evaluation Score of the Sound Quality is investigated for the combination which becomes the largest. According to the innovation tool which is developed this time, the condition search for improving the Sound Quality and the evaluation would be performed. The target of evaluation score should be exceeded 8.49 as standard value which is referred to reference products in the Sound Quality evaluation.

4.2. DETERMINATION OF THE LEVEL AND CONTROL FACTOR

Comprehensive evaluation of this software is performed to improve the Sound Quality in the experiment of the condition search. The control factors for the first trial are shown in Table 6. Four factors which is arranged Bleeder Resistor to control impedance that have impact to Sound Quality by current flowing as the control factors and three levels for each as Bleeder Resistor are set. Using L9 orthogonal array, it is calculated with the static characteristic which is created the Evaluation Score to the nominal-is-best response.

This experiment is conducted with nine experiments on the conditions which are created to the control agent in L9 orthogonal array. It is calculated them like Section 2.1, and the response graph for the SN ratio is shown in Fig. 9.

Table 6. Control factors for trial regarding the Optical Disc Drive for sound quality evaluation

Control factors				
Name of factors	Bleeder Resistor R1 [ohm]	Bleeder Resistor R2 [ohm]	Bleeder Resistor R3 [ohm]	Bleeder Resistor R4 [ohm]
Level 1	3.3k	3.3k	3.3k	3.3k
Level 2	10k	10k	10k	10k
Level 3	1M	1M	1M	1M

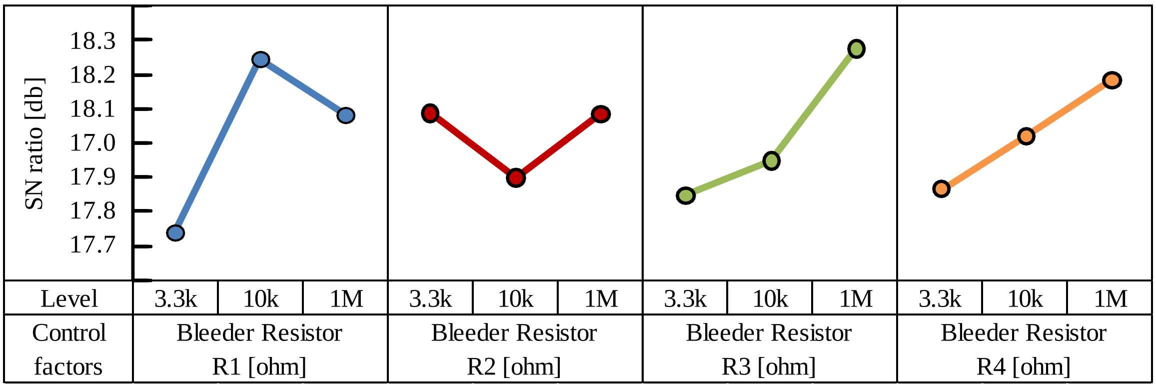


Fig. 9. Response graph for SN ratio diagram

In the Taguchi-methods, it would be a target for consideration as final result. Based on the result of Fig. 9, the average value and standard deviation of characteristic values are calculated for each control factor in the software of this development. The complete the curve from (a) to (d) in Fig.10 that is selected polynomial approximation (square) for an approximated curve. According to that curve, these are the results of calculated for the optimal level within the software.

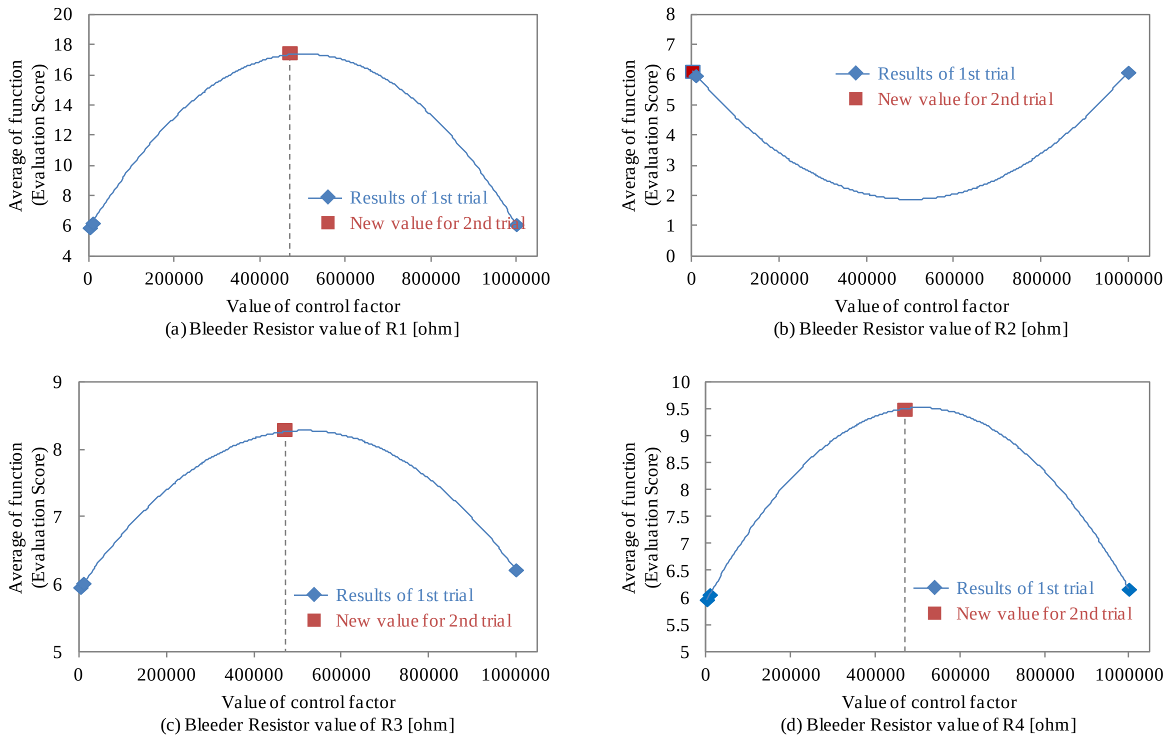


Fig. 10. Recommendation of the level for 2nd trial using 1st trial results

SN ratio of approximated curve has a combination of four resistance to be maximum value that should be maximized Evaluation Score of Sound Quality in the second trial.

4.3. EVALUATION OF THIS SYSTEM

The combination for confirmatory experiment is showed that determined the consideration of Section 4.2 in Table 7. The Evaluation Score of the Sound Quality for each Tuning Method is shown in Fig. 11. Evaluation Score could be satisfied by applying both the experiment of L9 along with Taguchi-method and the Software which is developed this time. In addition, the result is equivalent to determine the level with Try & Error method which is performed by the Sound Meister.

By the conventional method, total 150 examinations are required in order to reach the target. On the other hand, this method is ended by 10 times to be able to optimize for equivalent values. Thus, it is performed efficiently to achieve to the target, and the number of time is gone up to 15 times.

According to this examination, the second trial is required only to check the status. The reasons are that; (1) Based on the first trial result, the control factors and the level for the second trial could be promised a certain level of effect (2) Narrowing down of a constant would be difficult because the sensitivity of factor is become high.

Table 7. Results of the resistance value calculated

Resistor R1 [ohm]	Resistor R2 [ohm]	Resistor R3 [ohm]	Resistor R4 [ohm]
470k	3.3k	470k	470k

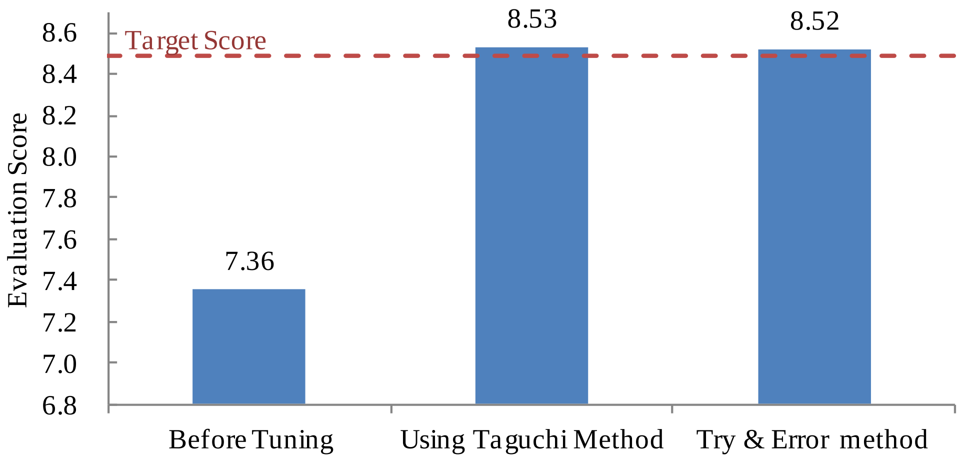


Fig. 11. Comparison of the results

5. CONCLUSION

From this research, it could be concluded that; (1) Sensory characteristic tuning method by using Taguchi-methods is calculated the values to be optimized in a few studies, and the result is equal to or greater than the result of Sound Meister is implemented. (2) Commonly, the sensory characteristic of optimization is conducted with Try & Error method; however, it is confirmed that leading the improvement of productivity by using this method.

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